Resource sharing and blocking

The Mars Pathfinder
Unbounded priority inversion
Priority inheritance

Lecture overview

- Unbounded priority inversion problem (occurred in the Mars Pathfinder)
- Blocking and the priority inheritance protocol

- Multithreading and synchronization
  - **Semaphores** are the most common mechanism
  - Supported by the PThreads library

What really happened on Mars?

Source: NASA JPL

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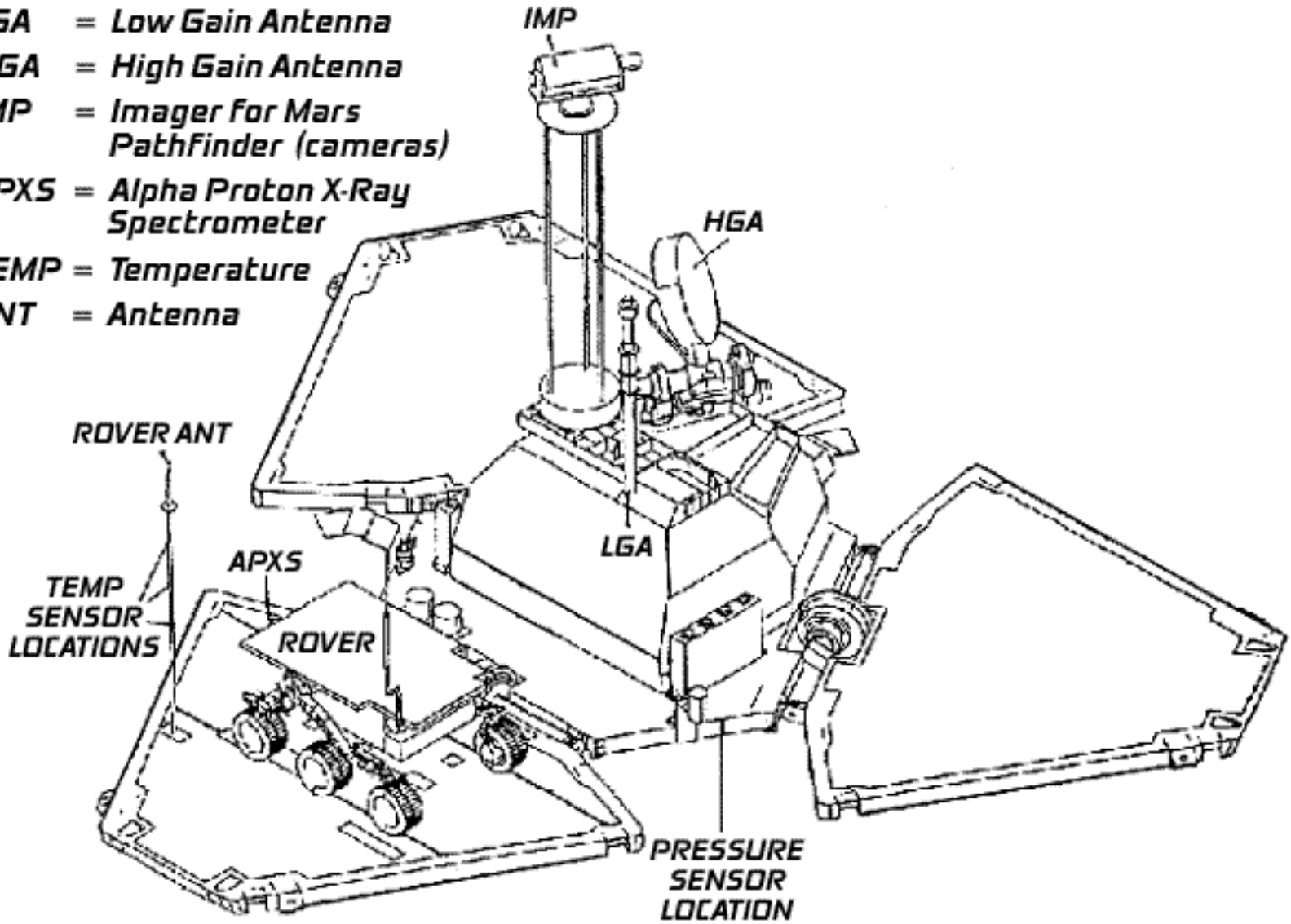
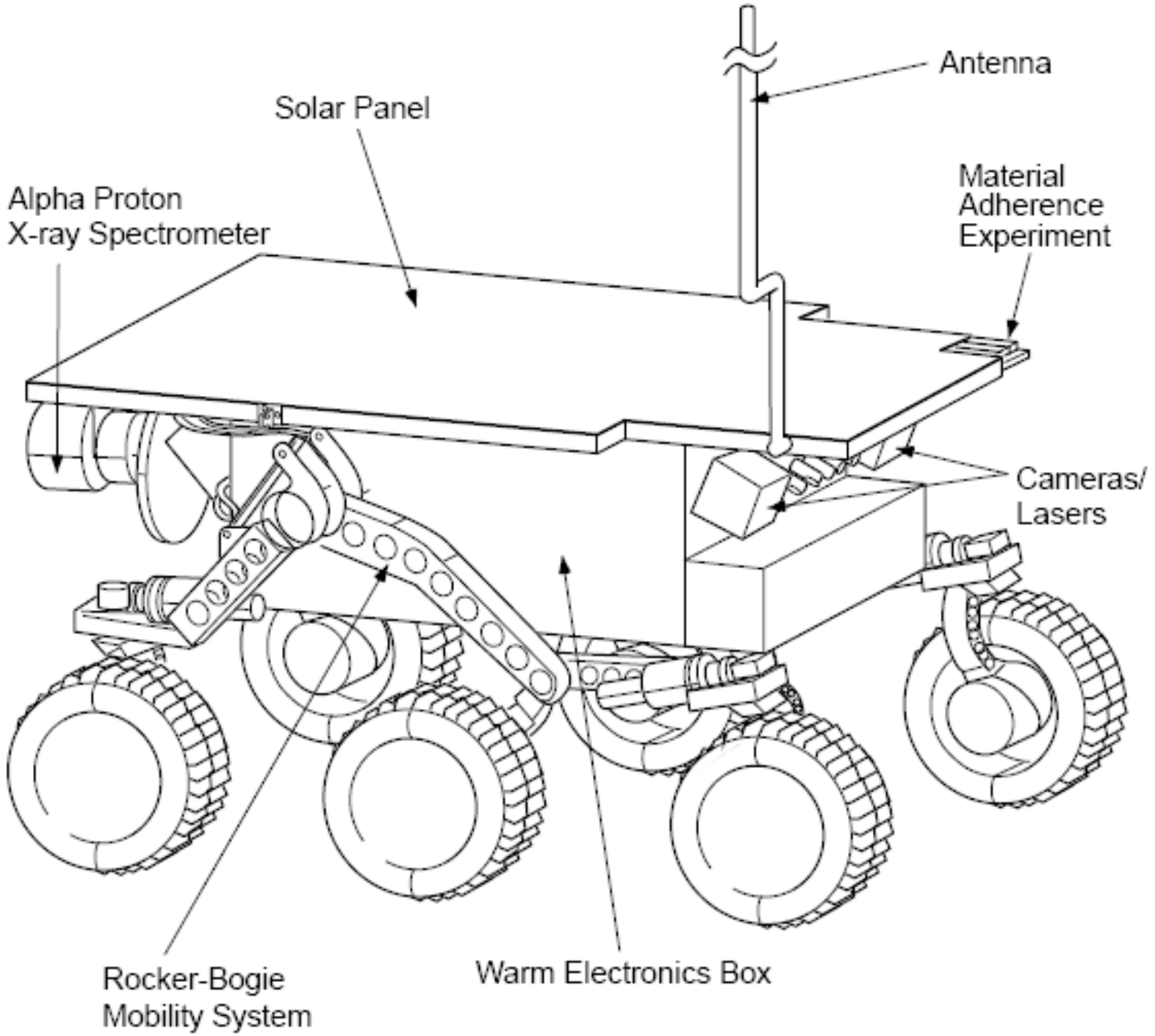
Mars PathFinder

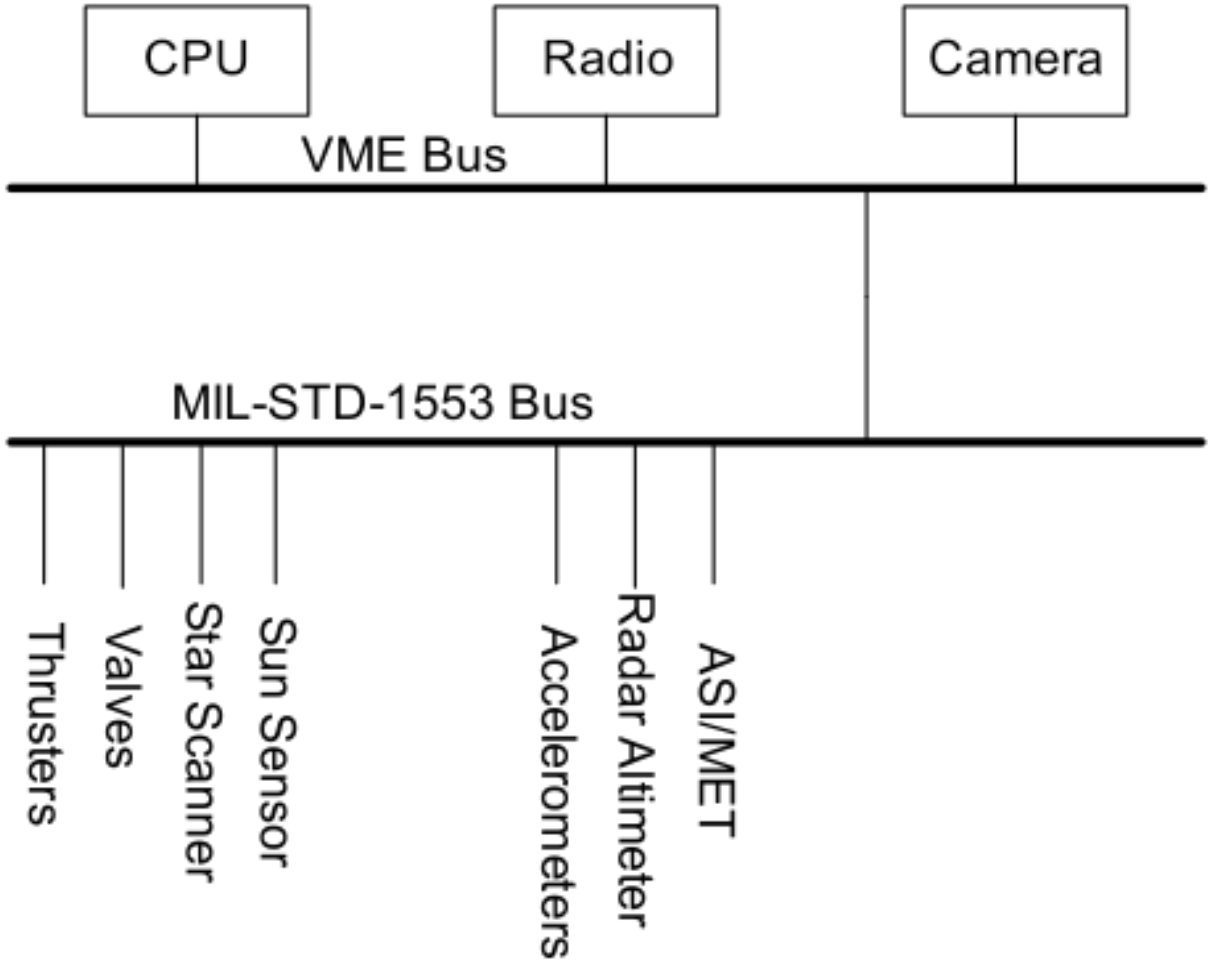
LGA = Low Gain Antenna
HGA = High Gain Antenna
IMP = Imager for Mars Pathfinder (cameras)
APXS = Alpha Proton X-Ray Spectrometer
TEMP = Temperature
ANT = Antenna



Source: Jet Propulsion Laboratory, 1994


Antenna
Solar Panel
Alpha Proton
X-ray Spectrometer
Material
Adherence
Experiment
Cameras/
Lasers
Rocker-Bogie
Mobility System
Warm Electronics Box

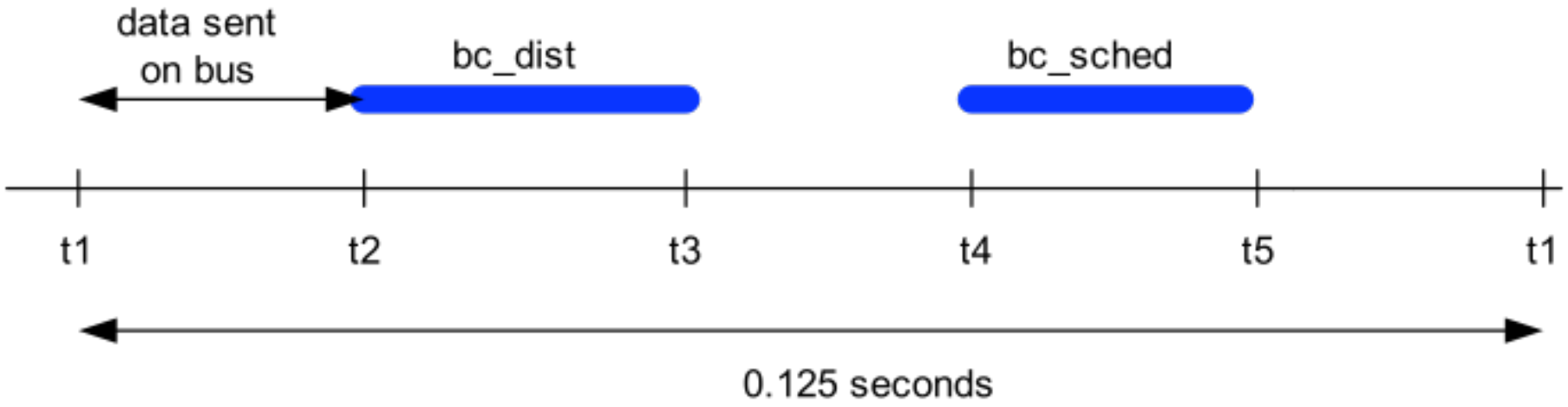
Mars Pathfinder



Mars Pathfinder

- Many important tasks
- bc_sched: plans transactions on the 1553 bus
  - highest priority task
- bc_dist: gathers data from the 1553 bus
  - third-highest priority task
- lots of medium-priority tasks
  - asi/met: handles data collection for scientific experiments
  - low priority task

Schedule

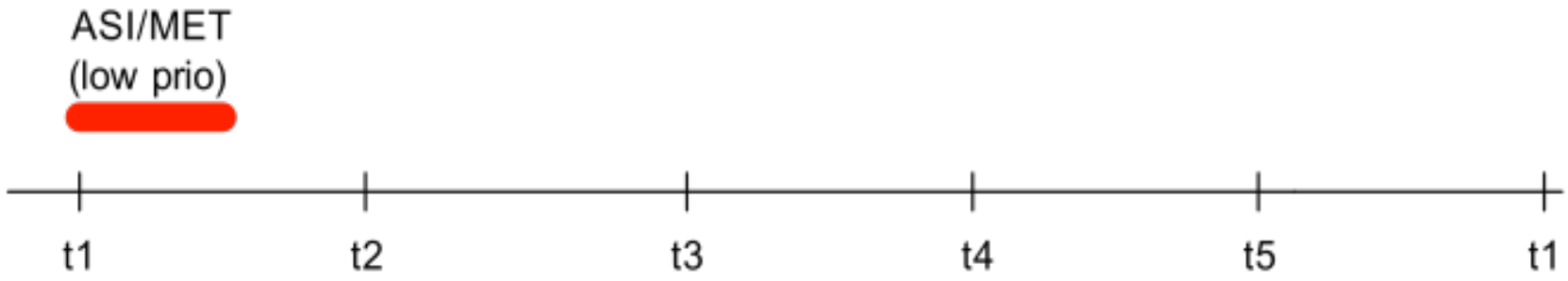


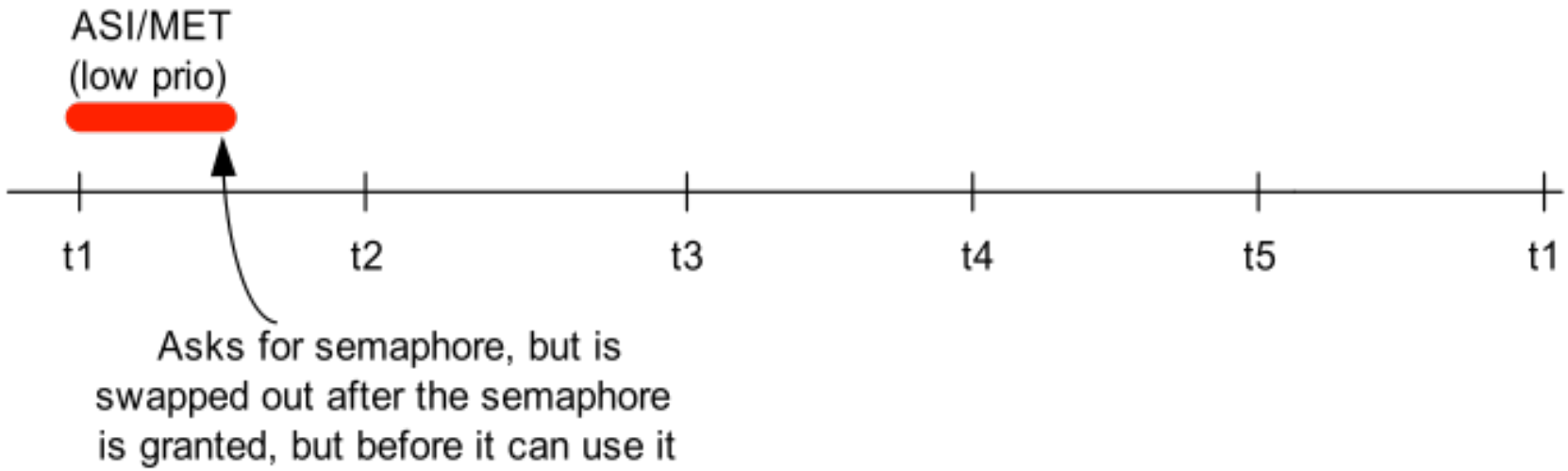
T = 0.125 seconds

The first thing bc_sched would do is make sure that bc_dist had finished;

if not, it would reset the system (so the Deadline for bc_dist was t4)


t1
t2
t3
t4
t5
t1


ASI/MET
(low prio)
t1
t2
t3
t4
t5
t1


ASI/MET
(low prio)
t1
t2
t3
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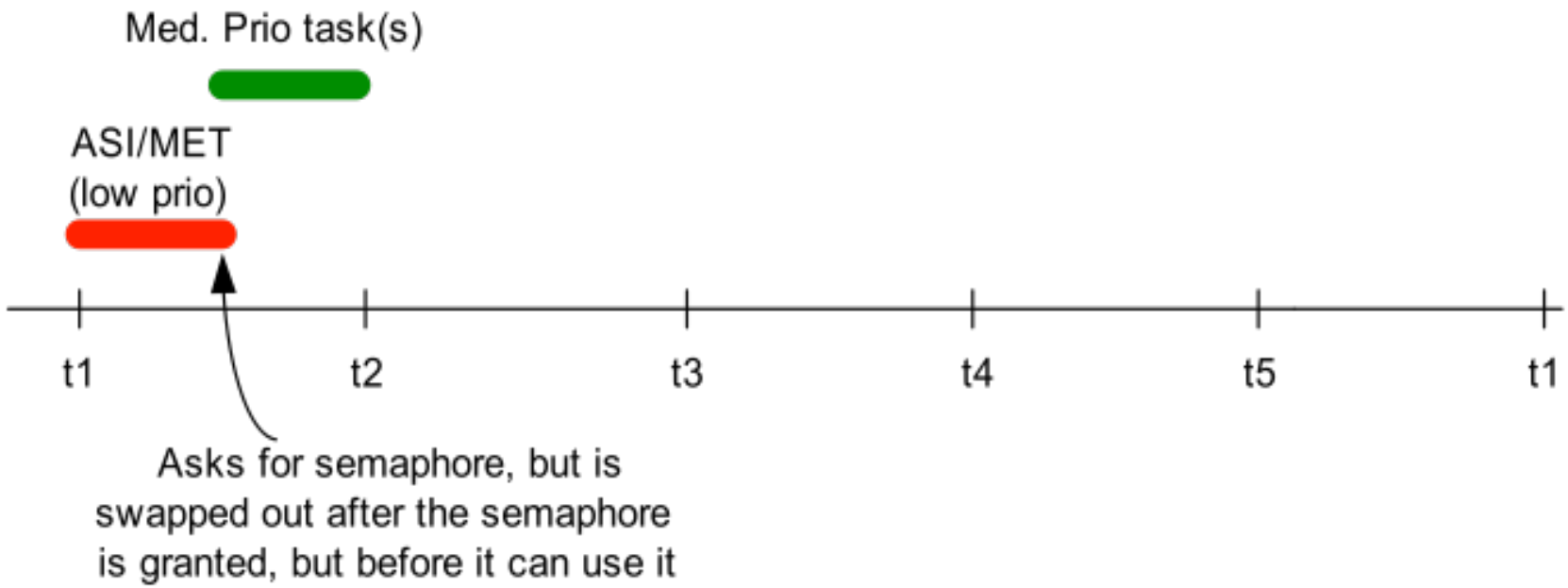
t5
t1
Asks for semaphore, but is
swapped out after the semaphore
is granted, but before it can use it


Med. Prio task(s)
ASI/MET
(low prio)
t1
t2
t3
t4
t5
t1
Asks for semaphore, but is
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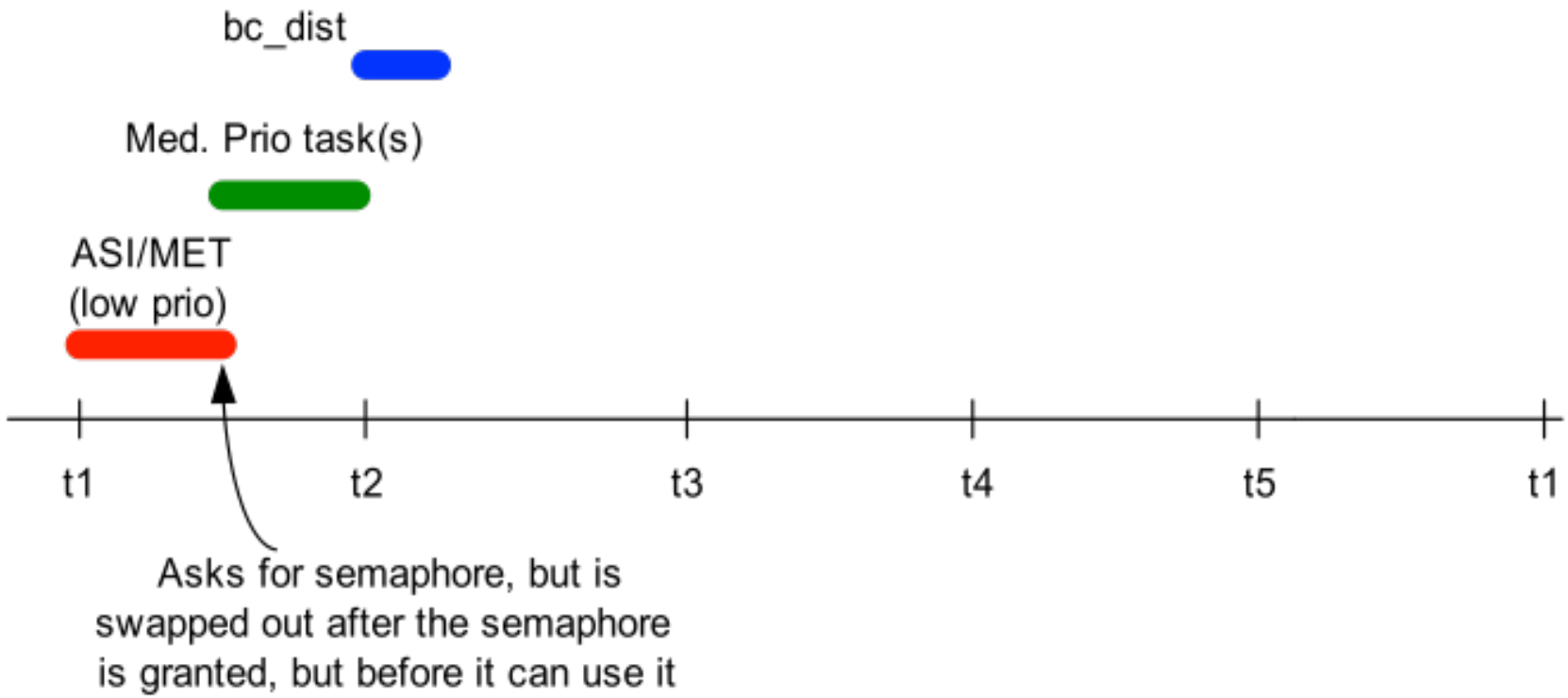
bc_dist
Med. Prio task(s)
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t2
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Asks for semaphore, but is
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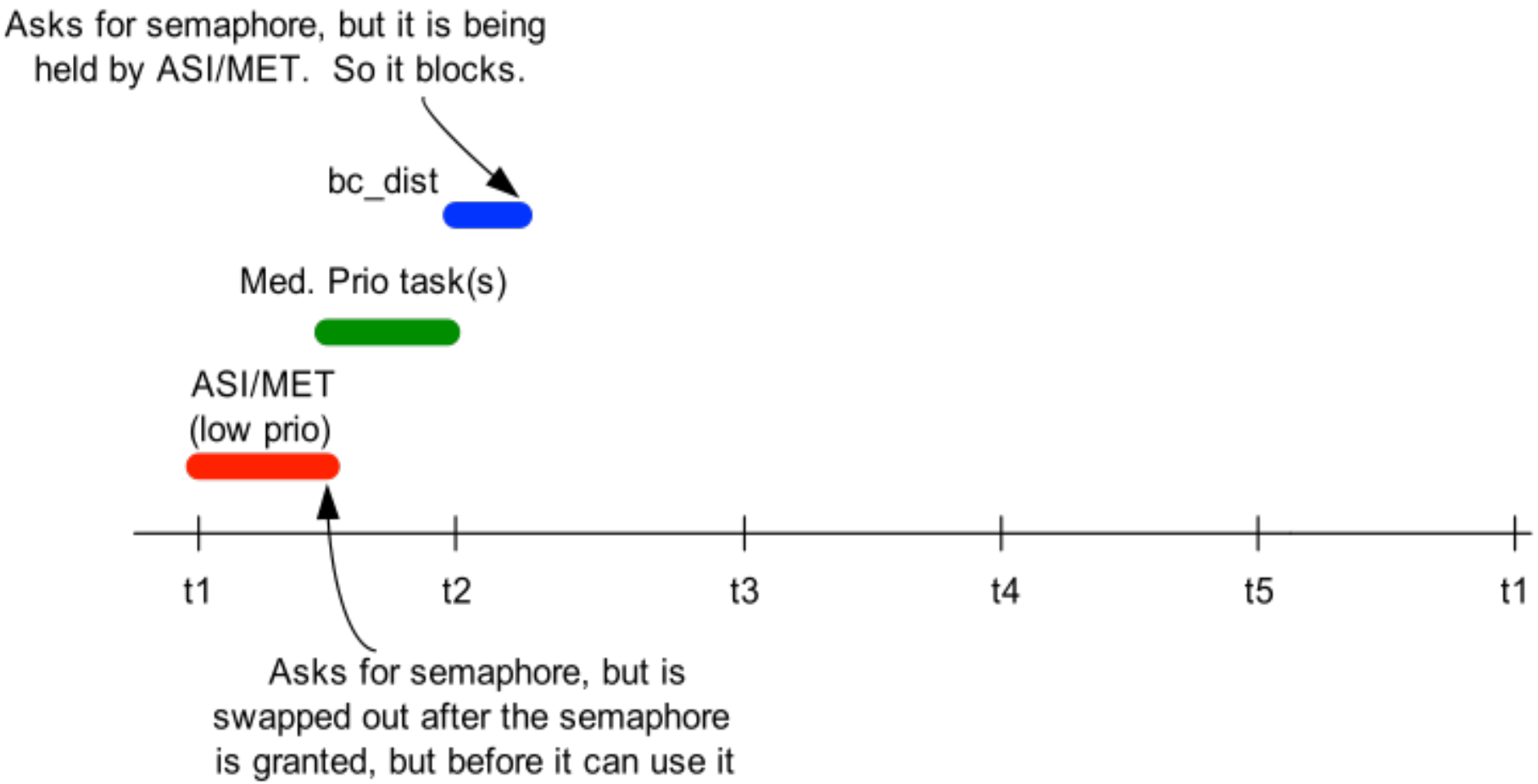
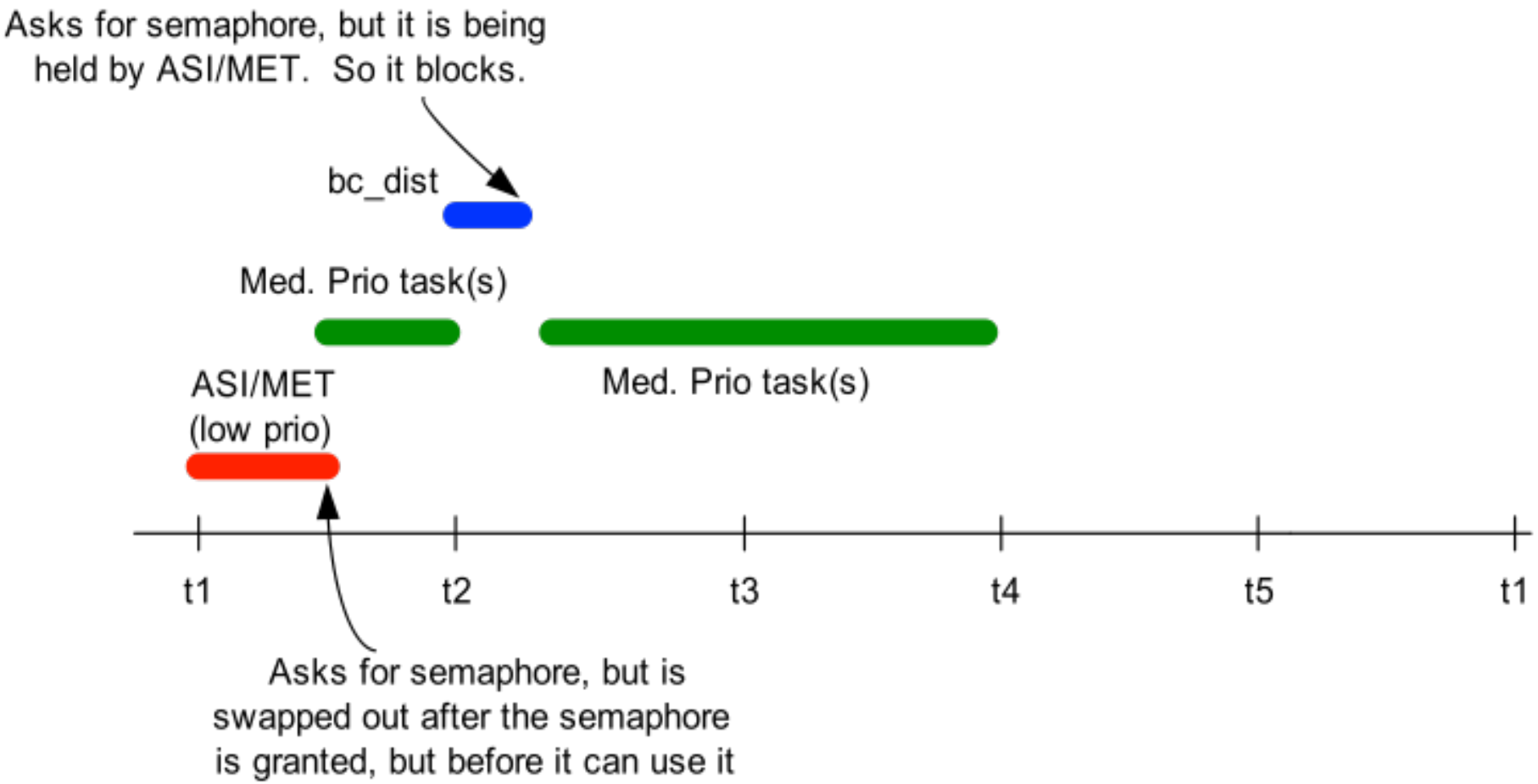

Asks for semaphore, but it is being held by ASI/MET. So it blocks.
bc_dist
Med. Prio task(s)
ASI/MET (low prio)
t1
t2
t3
t4
t5
t1
Asks for semaphore, but is swapped out after the semaphore is granted, but before it can use it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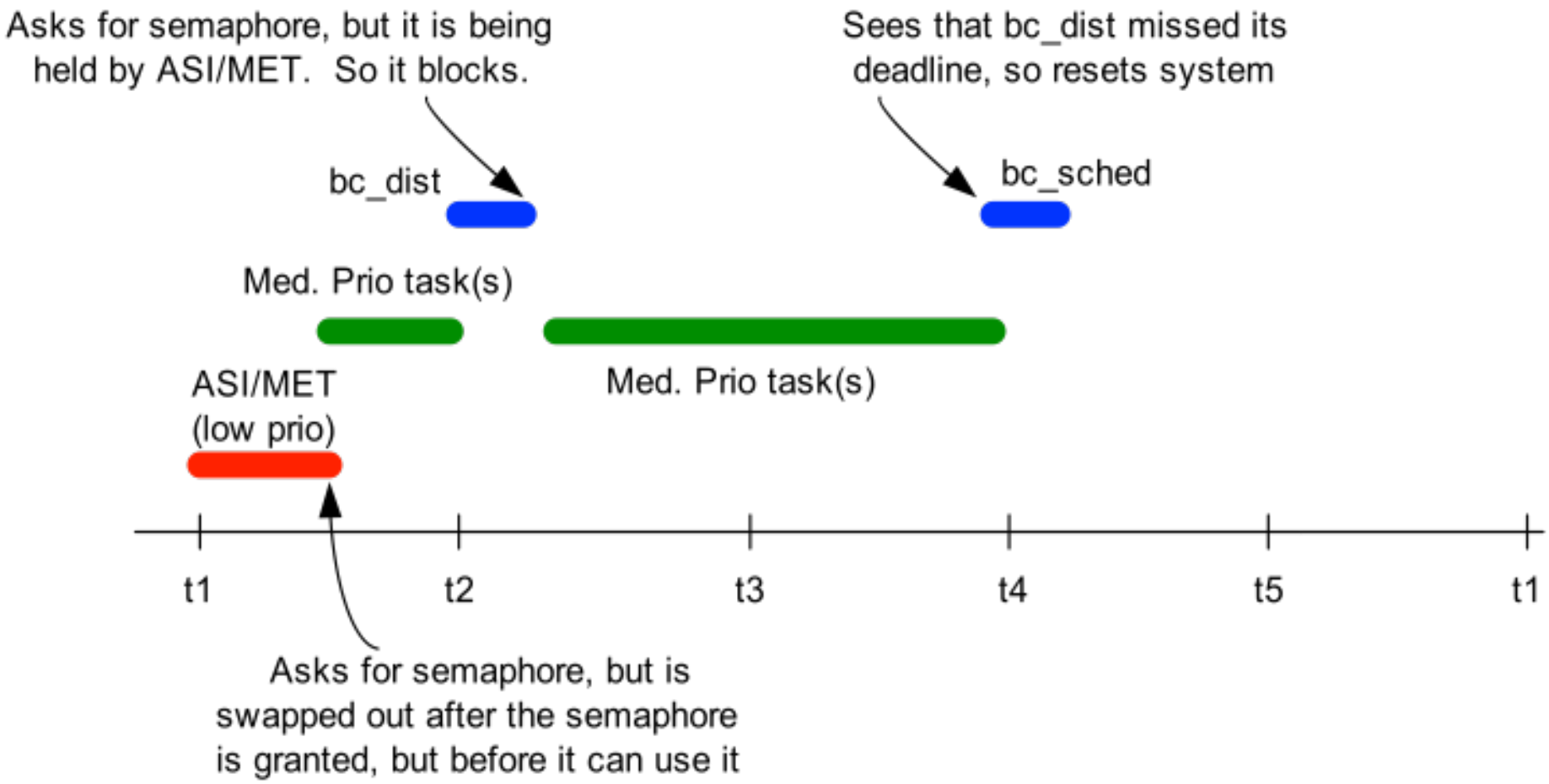


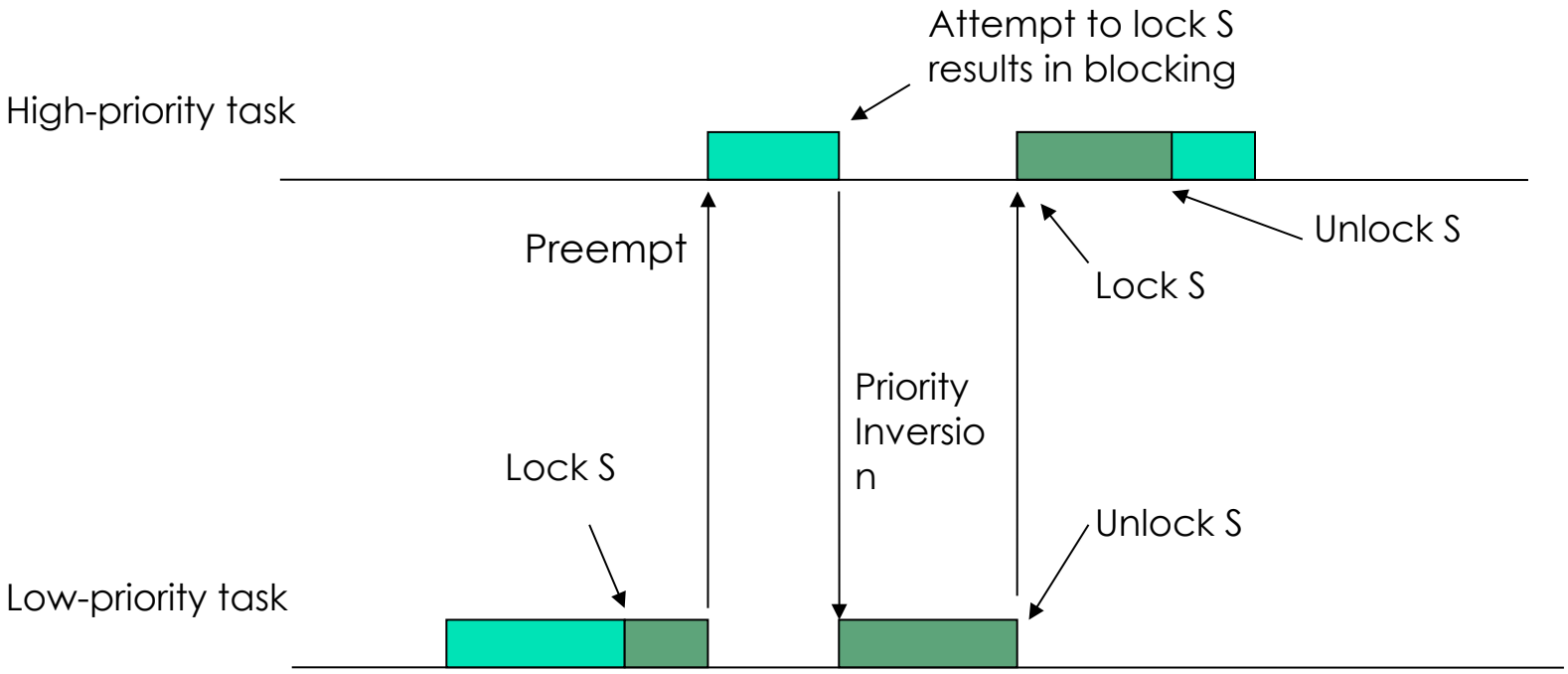
This phenomenon is called Priority Inversion.

Blocking

- Tasks have synchronization constraints
  - Use semaphores to protect critical sections
- Blocking can cause a *higher priority task to wait for a lower priority task to unlock a resource*
  - We always assumed that higher priority tasks can preempt lower priority tasks
  - As it turns out, that may not be the case... so how do we make the priority rules consistent

The priority inheritance protocol

- Allow a task to **inherit the priority** of the highest priority task that it is blocking



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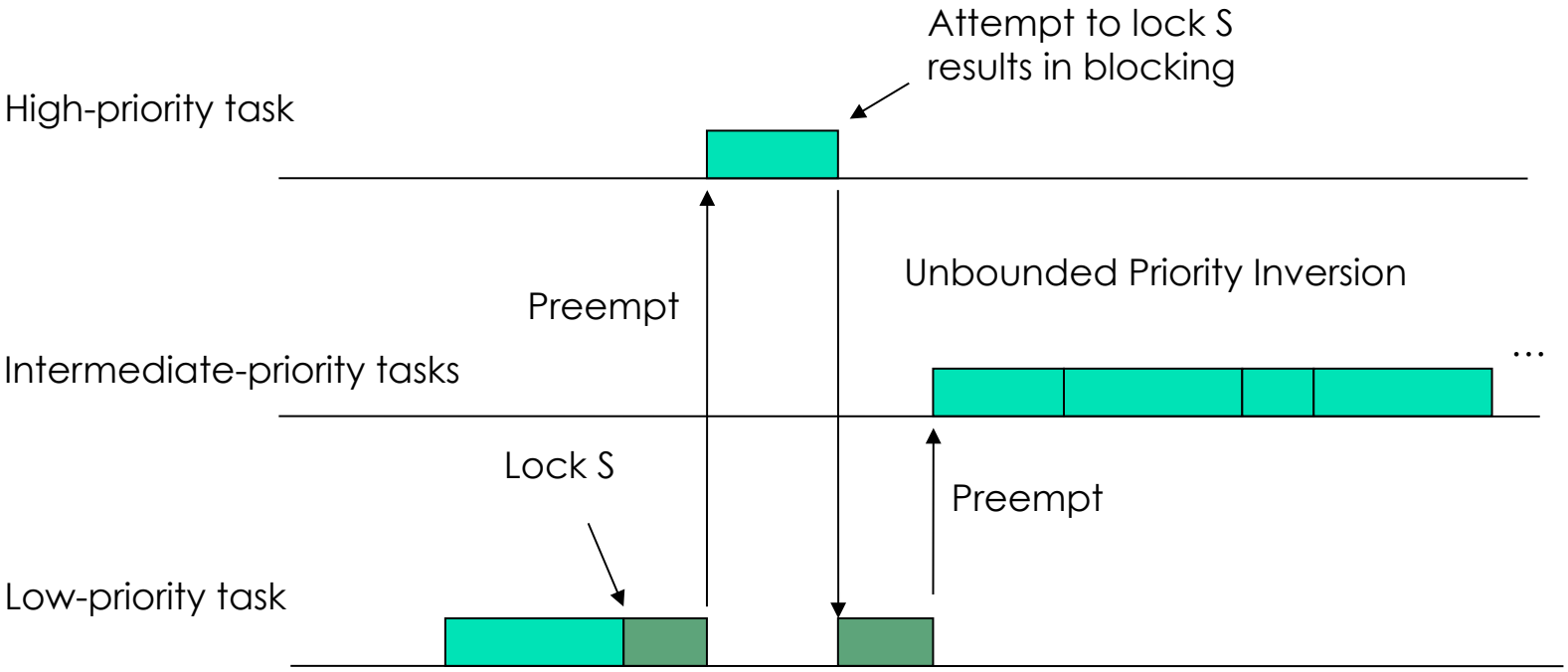

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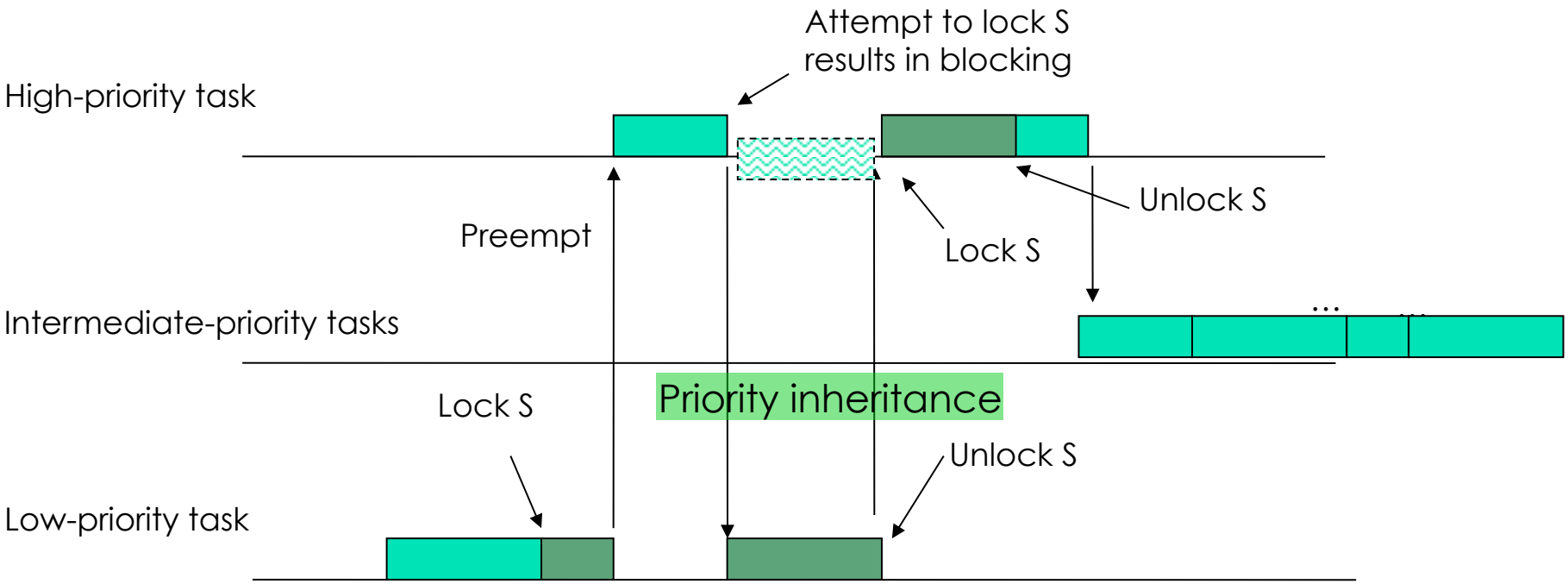


The importance of good theory

- [Speaking on the Mars Pathfinder problem at the Real-Time Systems Symposium 1997] David [David Wilner, CTO, WindRiver Systems and makers of VxWorks] also said that some of the real heroes of the situation were some people from CMU who had published a paper he'd heard presented many years ago who first identified the priority inversion problem and proposed the solution. He apologized for not remembering the precise details of the paper or who wrote it. Bringing things full circle, it turns out that the three authors of this result were all in the room, and at the end of the talk were encouraged by the program chair to stand and be acknowledged. They were Lui Sha, John Lehoczky, and Raj Rajkumar. When was the last time you saw a room of people cheer a group of computer science theorists for their significant practical contribution to advancing human knowledge? :-) It was quite a moment.

- From "What really happened on Mars?"

  - Mike B. Jones, Microsoft; http://research.microsoft.com/~mbj/Mars_Pathfinder/Mars_Pathfinder.html

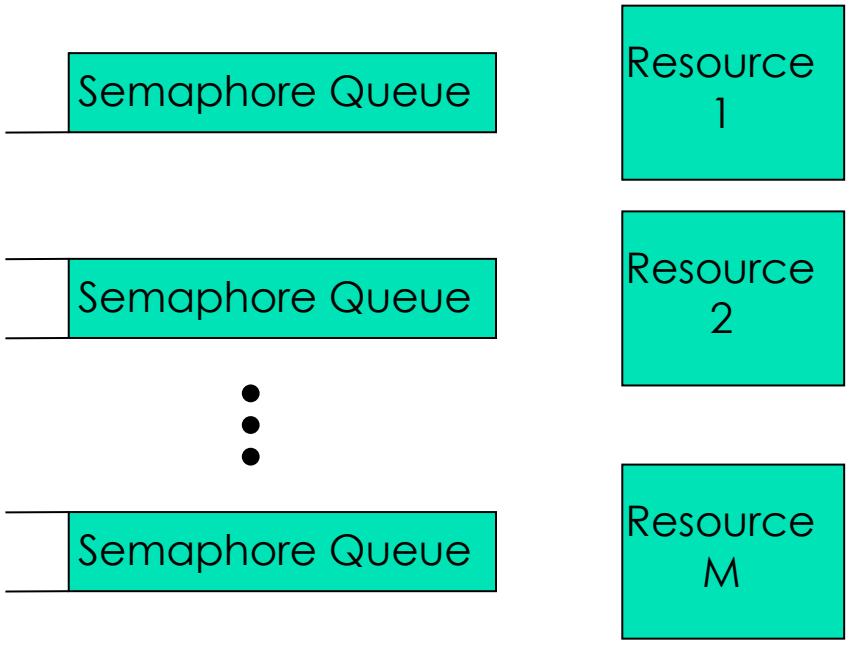
  - For the record, the paper was: L. Sha, R. Rajkumar, and J. P. Lehoczky. Priority Inheritance Protocols: An Approach to Real-Time Synchronization. In IEEE Transactions on Computers, vol. 39, pp. 1175-1185, Sep. 1990.

Blocking time

- What is the longest time a task can be blocked (waiting for lower priority tasks to release a resource)?
  - Let there be *N* tasks and *M* semaphores
  - The length of the largest critical section of Task T_i is B_i

Blocking time

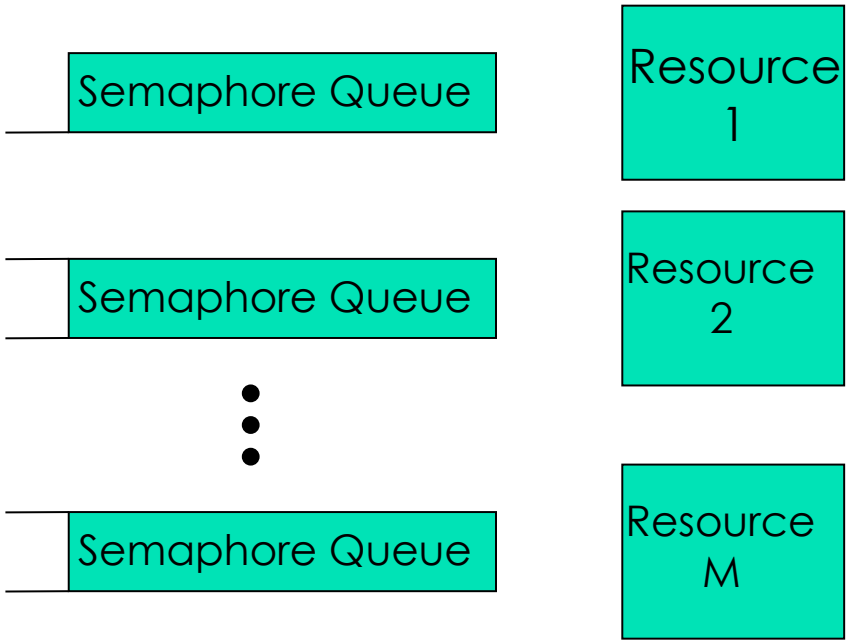
- Consider the instant when a high-priority task arrives
  - What is the maximum length of time it may need to wait for a lower priority task to finish?



If I am a task, priority inversion occurs when
(a) Lower priority task holds a resource I need (direct blocking)
(b) Lower priority task inherits a higher priority than me because it holds a resource the higher-priority task needs (**push-through blocking**)

Maximum blocking time

- If all critical sections are of equal length, B
  - Blocking time = *B* x *min(N, M)*
  - Why?
  - And what if the critical sections are of differing lengths?



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Maximum blocking time

- If all critical sections are of equal length, B
  - Blocking time = *B* x *min(N, M)*
  - Why?
- And what if the critical sections are of differing lengths?
  - Find the maximum length critical section for each resource
  - Add the top *min(N, M)* sections in size
  - The total priority inversion time experienced by Task T_i is denoted B_i
- **Remember: when computing the blocking time, you need only consider tasks with lower priority.**

Highlights

- We discussed the **unbounded priority inversion problem** and the impact of **blocking** on a high-priority task.
- A high-priority task is blocked when a low-priority task holds a resource (maybe a semaphore) that the high-priority task needs.
- Unbounded priority inversion can be avoided if we use the **priority inheritance protocol**.
- For schedulability analysis, we need to determine the **maximum blocking time** a task can experience. This can be computed by considering the resources used by lower priority tasks.